

3rd Quarterly Report  
Period of 10 October 1962 to 10 January 1963

[FUEL CELL ASSEMBLIES]

Prepared for

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## 1. SUMMARY

The objective of this program is to design, develop, and deliver multicell regenerative hydrogen-oxygen fuel cell assemblies to the Jet Propulsion Laboratories, Pasadena, California. The work is being carried out under JPL Contract 950258 (Fuel Cell Assemblies).

The major accomplishments during the first quarter consisted of the mechanical design of the first multicell unit as well as the material studies and component tests for this unit. Fabrication techniques and test procedures were established for all component parts.

The major accomplishments during the second quarter consisted of the fabrication, assembly, and preliminary testing of the first full scale prototype unit. Heat transfer design calculations were also conducted during this period. This report describes the results of work performed for the three month period from 15 October 1962 to 15 January 1963.

The major accomplishments during this period consisted of testing the first full scale prototype unit, conducting additional single cell component tests, as well as initiating the development of the final units. A total of 25 cycle tests have been conducted on the first prototype (which contains 31 series connected cells). The power output of this unit was found to range from 28 watts at 1 amp to 176 watts at 8 amps. Typical operating voltages at 4.5 amps ( $30 \text{ m.a./cm}^2$ ) are 51 volts (1.64 volts/cell) on charge and 25 volts (0.8 volts/cell) on discharge. The upper capacity limit of this unit was found to be 20 amp-hrs with little or not float charge. The float charge requirements were found to increase rapidly with state of charge beyond the 25 amp-hr level. The lower discharge limit was found to be equivalent to approximately 8 amp-hrs. Studies were initiated to determine the cause for the inability of the unit to discharge below this level. Charging voltages

were found to be relatively constant (within a few percent) from the beginning to the end of the charge period. Discharge voltages were also found to be constant (within a few percent) for the major portion of the discharge period. A gradual decline of voltage was observed near the end of the discharge period. Single cell component tests have indicated that significant increases in the upper capacity limit may be achieved by increasing electrolyte bed thickness. The bed thickness of the final units will be double that of the current prototype. Development of these units was initiated and has proceeded on schedule. Assembly and test of the first such unit should be conducted in early February 1963.

## 2. DESCRIPTION OF CELLS

The following section contains a description of the first full-scale prototype as well as the final units which are currently being fabricated.

### 2.1 Prototype

The first full-scale prototype is shown in Fig. 1. The two gas cylinders are made of 304 stainless steel and have internal diameters of 12-1/2 inches and wall thicknesses of 3/8 inch. The large cylinder encloses the cell stack and contains hydrogen while the small cylinder encloses the teflon bellows and contains oxygen. Twelve-bolt holes are located in the flanges of each of the cylinders as well as the base plate. The unit is fastened together with 1/2 inch high strength bolts and flexloc nuts.

The base plate is also made of 304 stainless and contains gas passages to connect the hydrogen and oxygen manifolds of the cell stack to their respective gas chambers. The same passages are also connected to external fittings in order that the unit may be operated in the primary mode of operation as well as for the initial flushing procedure during startup.

The unit contains 31 series connected cells. The cylinders and base plate are connected to the positive terminal of the cell stack and an insulated lead passes through the base plate and is connected to the insulated center bolt through the cell stack, which in turn is connected to the negative terminal of the cell stack.

The cell spacers (7 inches diameter and 1/4 inch thick) are made of nickel plated lucite (Plex 55). The main hydrogen and oxygen manifold holes are located opposite each other on the outside edge of each spacer. Small O-rings are used to seal the manifold passages.

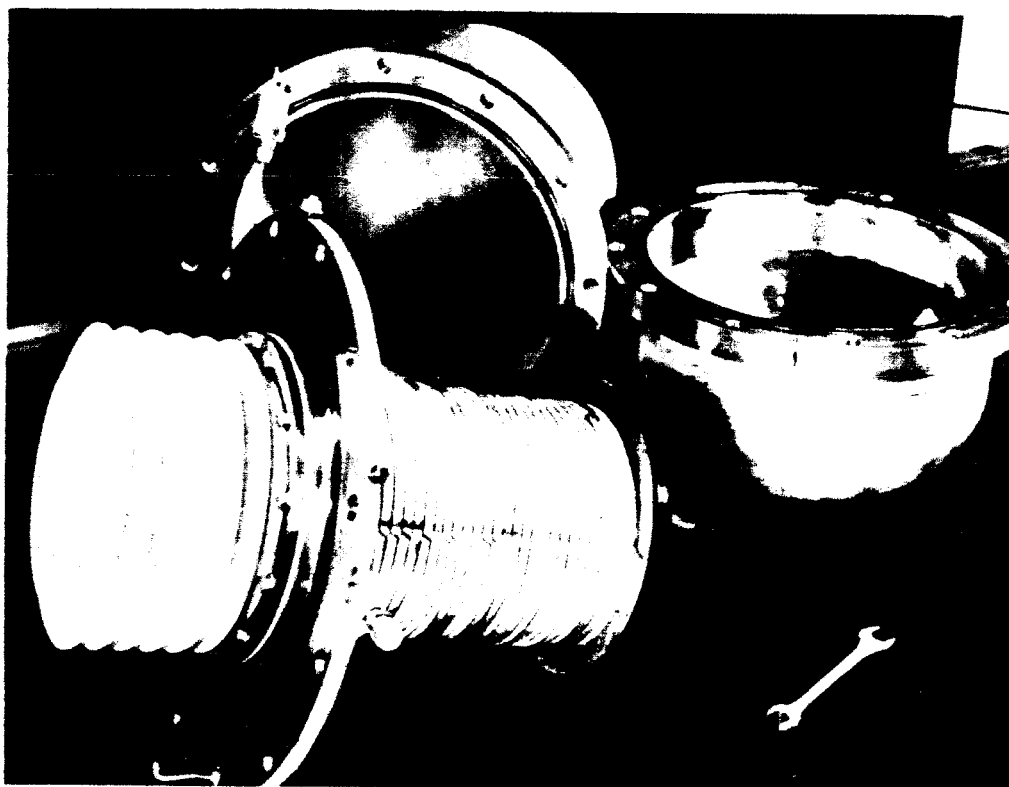


FIG. 1 FULL SCALE PROTOTYPE

Inlet hydrogen and oxygen manifolds within each spacer connect the main manifold lines to their respective electrodes.

Both hydrogen and oxygen electrodes are identical and consist of platinized porous nickel with 50 mg of platinum black per square inch. The diameter of the electrodes is 5-3/4 inches and the thickness is 22 mills. A two-inch diameter hole is cut in the center of each electrode. The electrodes fit within a recessed area on either side of each spacer. The electrolyte bed consists of two layers of sheet asbestos impregnated with 26 percent potassium hydroxide solution at 0.60 gms of solution per square inch. The outside diameter of the asbestos layers is 6-1/4 inches and the thickness of each sheet (in the dry state before impregnation) is 1/32 inch. A 1-1/2 inch diameter hole is cut through the center of each layer.

A teflon bellows is fastened to the back side of the base plate and serves as a pressure equalizing device for the gases within each chamber.

## 2.2 Final Units

The final units will be essentially the same as the first full-scale prototype. There will, however, be two differences. The first is that each cell of the final units will contain four layers of the potassium hydroxide impregnated asbestos (as compared with two layers for the prototype). The second is that the material of construction of the gas cylinders and base plate will be an aluminum alloy, 6061-T6, for the final unit (as compared with 304 stainless for the prototype).

One minor difference is that the negative electrical lead will be taken out via a copper lead wire which passes through an insulated gland within the flange on the hydrogen cylinder.

The final unit will contain 38 cells. The weight of the complete unit is estimated at 80 pounds.



### 3. PROTOTYPE TESTING

The following section gives the results of all tests conducted on the first full-scale prototype assembly.

#### 3.1 Preliminary Tests

As indicated in the last quarterly report (3070-Q-2) the first prototype had been assembled with a stack of 34 cells, and preliminary cycle tests were initiated in the true secondary mode of operation. The first such tests consisted of several short cycles at the 2 amp-hr level. During the last day of that reporting period, a longer cycle at the 10 amp-hr level was initiated. In this latter test, the unit was placed on stand overnight at the 10 amp-hr state of charge (which corresponded to gas pressure near 100 psig). At the end of a 12-hr stand, it was observed that a small leak had developed within the large O-ring groove in the cylinder flange and had caused the gas pressures to drop from 100 to 80 psig.

The unit was subsequently disassembled, the surfaces of the flanges were remachined, and the surface of the base plate was polished in order to provide a better O-ring seal.

Before continuing with the longer cycle tests at the 20 and 30 amp-hr levels, a proof test was conducted on the newly machined gas cylinders. This test consisted of filling the gas cylinders with water and then applying nitrogen gas pressure at 600 psig. The test resulted in the deformation of the flanges and subsequent leaks within the large O-ring. The deformation of the flanges made it impractical to attempt to repair them. New cylinders with thicker and stronger flanges were immediately designed and sent to an outside vendor for fabrication.

### 3.2 Rework

During the period required for fabrication of the new cylinders, it was decided to make slight modifications upon and thereby improve the performance of the cells within the stack. The unit was then completely disassembled and the following modifications were made.

First, the old set of electrolyte beds was discarded and a new set was prepared. The new set was made with a slightly smaller outside diameter (1/16 inch less) and a slightly larger inside diameter (1/16 inch greater). The purpose of this change was to reduce the amount of asbestos on the sealing area within each cell and thereby increase the per unit area compression loading.

Another modification was carried out to ~~prevent~~ the breakdown of the battery terminal as described below. During the course of assembling the cell stack, it had been observed that a small amount of electrolyte had been dislodged from the cells, drained to the bottom of the center tie bolt and become absorbed and reacted with the phenolic bushing which serves as an insulator between the battery terminals. When the assembly was charged in the 50 to 60 volt range, this bushing had become burned out and caused an internal short circuit. In order to prevent this phenomena from occurring again, the amount of electrolyte added to each cell was controlled at a lower level (1 gm less than the previously employed amount of 20 gms) and as an added measure the phenolic bushing was replaced with a nylon bushing which is inert to the basic electrolyte.

A final modification consisted of cleaning all of the electrodes by immersing each one several times in boiling distilled water. This process had been experimentally shown to restore the activity of used electrodes which had been exposed to the atmosphere. The leaching process removes the excess film of KOH solution and possible contaminants

such as  $\text{CO}_2$  which may have been absorbed on the surface by exposure to the atmosphere.

### 3.3 Reassembly

Upon re-inspection of the nickel plated plastic spacers, it was found that there were three which were defective and were therefore discarded. Two of these spacers had been adjacent to the phenolic bushing and were damaged slightly by the internal electrical short. The third was excessively corroded on its surface. The cause for the corrosion must have been an incomplete nickel plating which caused access and subsequent reaction of the potassium hydroxide solution with the substrate copper layer. The unit was therefore reassembled with 31 of the original 34 cells.

The stack of 31 cells ~~was~~ then mounted on the base plate and voltage probes were made of each of the cells for the quasi-secondary type of operation as described previously. On discharge at 2 amps and at 10 psig gas pressure, the voltages of 30 of the cells ranged from 0.77 to 0.96 volts and the voltage of one cell was 0.65 volts. On charge at 4.0 amps, the voltages of all 31 cells ranged from 1.59 to 1.62 volts. The unit was then cycled once at the 20 amp-hr level and this mode of operation was terminated.

The teflon bellows was mounted on the base plate as shown in Figure 1 and the assembly was placed within the new gas cylinders. The completed assembly was instrumented with hydrogen and oxygen pressure gages and two thermocouples; one of which was in contact with a cell inside the gas cylinders and one of which was in contact with the outside surface of the gas cylinders. The air within each of the gas cylinders was replaced with 1 atmosphere each of hydrogen and oxygen gases by flushing each cylinder with its respective gas for several hours at flow rates of 10 cfh. The complete assembly was then ready for true secondary operation.

### 3.4 Voltage-Current Characteristics

The voltage-current characteristics of the unit were measured at the end of a 10 amp-hr charge of the first cycle (with gas pressures

near 90 psig). The results of the voltage-current measurements for both charge and discharge are shown in Fig. 2. The results indicate that the voltage and power efficiencies (which are nearly identical for the cell) would be approximately 61 percent for a constant current cycle at 1.0 amp and 41 percent for a constant current cycle at 8.0 amp. The results also indicate that power outputs ranged from 28.5 watts at 1.0 amp to 176 watts at 8 amps (for 31 cells). The results may also be expressed in terms of volts per cell versus current density. Typical operating points at 30 m.a./cm<sup>2</sup> are 0.8 volts/cell on discharge and 1.64 volts/cell on discharge.

### 3.5 Voltage-Time Characteristics

The voltage-time characteristics of the unit for a complete charge-discharge cycle are given in Fig. 3a. The charge portion of the cycle was conducted at 6.0 amps and the discharge was conducted at 4.0 amps for the major portion of the discharge period. During the latter portion of the discharge period when the terminal voltage began to decline, the load was reduced to 2.0 amps and finally to 1.0 amp when the load was removed.

It should be noted that except for a short period of time at the beginning of charge, as well as the beginning and end of discharge, the terminal voltage is relatively constant for the major portion of both charge and discharge periods. Although no attempt has been made to explain the gradual rise and decline of voltages at the beginning of charge and discharge respectively, it should be pointed out that these characteristics correspond to those of single cells and also the same characteristics are noted on other types of secondary batteries. One possible explanation may be the build-up and decay of surface films of compounds other than hydrogen and oxygen at lower voltages than that required for the evolution of these gases on charge and at higher voltages than that attained by the reaction of these gases on discharge. Similarly, no complete explanation is available for the rapid decline in terminal voltage at the end of discharge even with residual gas pressures although some investigations are currently being conducted to explain

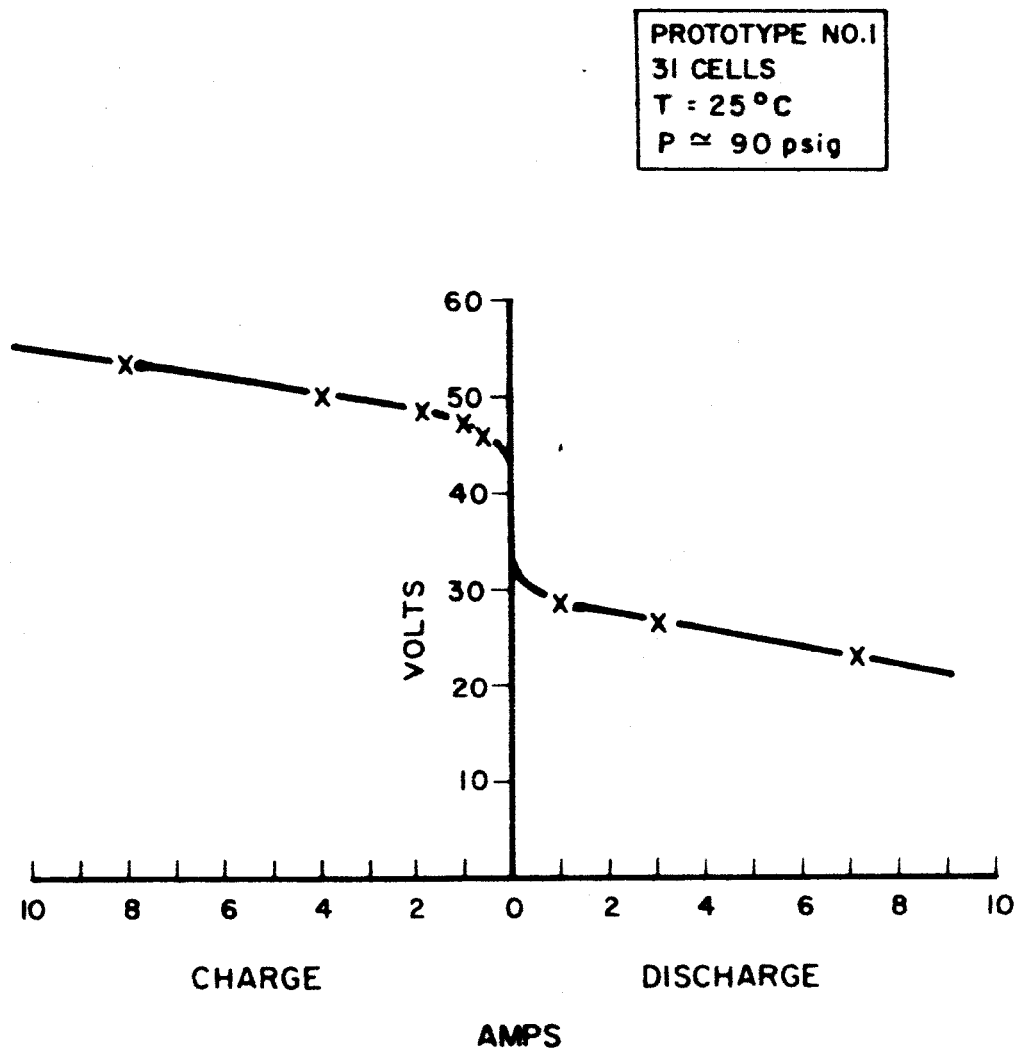


FIG. 2 VOLTAGE-CURRENT CHARACTERISTICS

this phenomena. It is possible that an accumulation of inert gases within the electrodes increases during discharge to such an extent that after approximately 10 amp-hrs of discharge, the concentration of inerts with the electrodes is so high as to cause the "limiting current" of the electrodes to be reached, and a corresponding rapid decline in terminal voltage.

### 3.6 Pressure-Time Characteristics

The pressure-time characteristics for the same cycle as above are given in Fig. 3b. Within the limits of experimental error the two gas pressures were equal (and should be so due to the action of the compensating teflon bellows) and therefore only one gas pressure need be plotted.

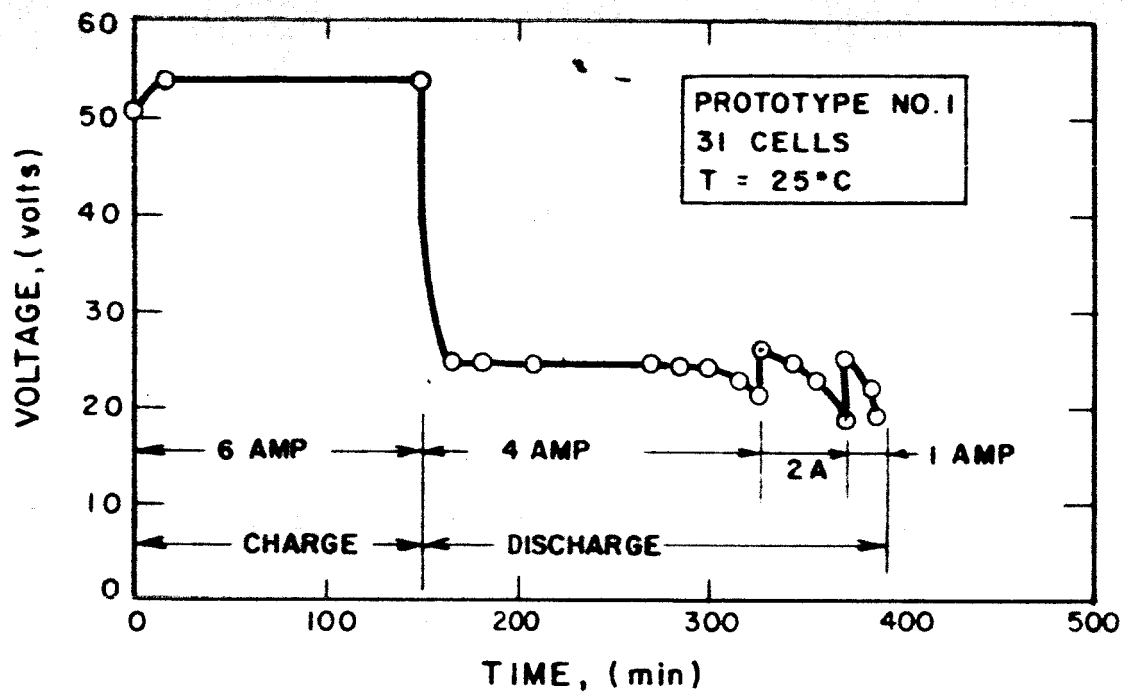
The slope of the linear pressure-time curves corresponds very closely with that which can be calculated from the known current, cylinder volume, and electro-chemical equivalent of the gases.

The slope of the various segments of the pressure-time curve when divided by the current gives a value of approximately 8.7 psi/amp-hr.

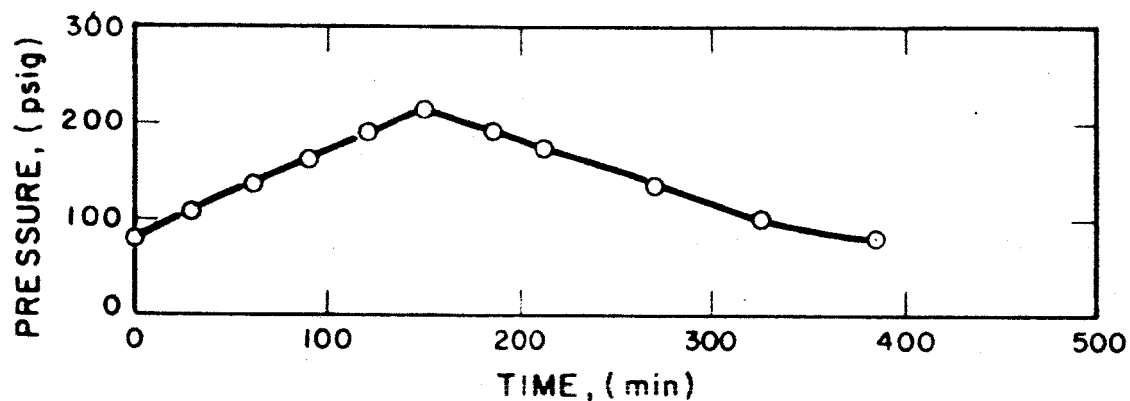
### 3.7 Temperature-Time Characteristics

The internal temperature of the unit (located on the outside edge of a spacer at the end furthest away from the base plate) for the same cycle is shown in Fig. 3c.

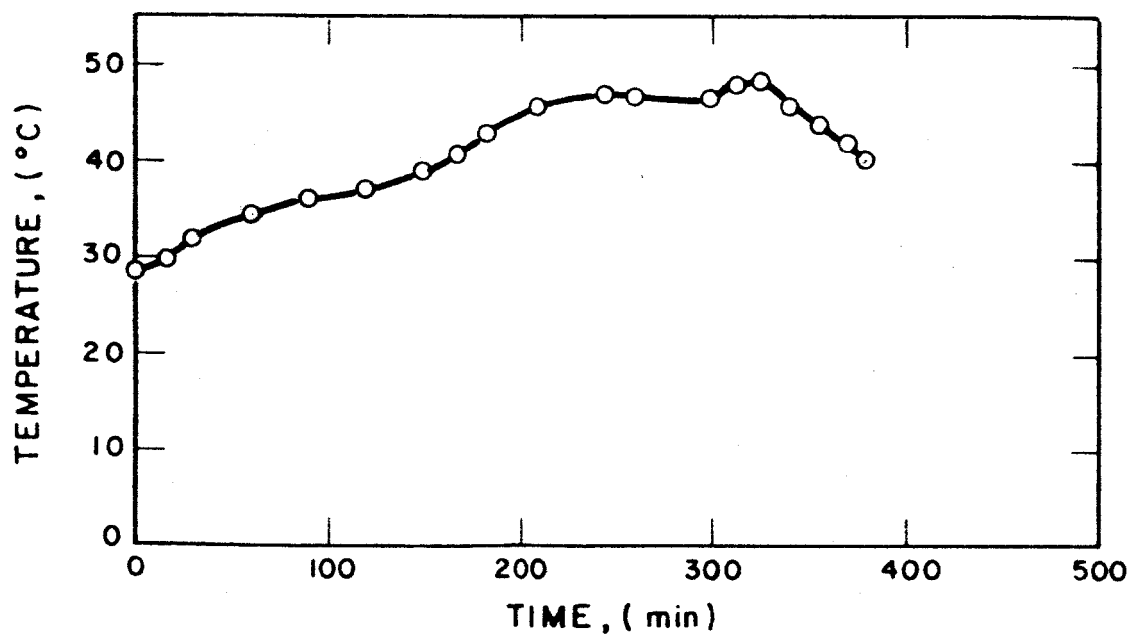
The slope of the temperature time curves can be qualitatively explained on the basis of a combined transient and steady-state heat transfer. During the initial portion of both the charge and discharge periods (the transient state) the major portion of the heat which is generated is absorbed by the thermal capacity of the fuel cell and therefore results in a relatively rapid rise of temperature. During the latter portion of the above charge and discharge periods, the temperature of the fuel cell has increased to such a point that the rates of heat generation and transfer from the cell are nearly identical. At this point (the steady-state) the cell temperature is nearly constant with



3a



3b



3c

FIG. 3 CYCLE CHARACTERISTICS

time. It should be pointed out that the difference between the steady-state temperatures for charge and discharge is due to the fact that the heat generation rates are different for each phase of the cycle.

### 3.8 Self-Discharge Characteristics

The purpose of the second cycle was to establish the maximum charge that the unit could accept and effectively retain. In this test, the unit was charged to the 25 amp-hr level (at which the gas pressures reached 211 psig) and then placed on stand for 30 hours. During the first few hours of this stand (see Fig. 4), there was a rapid decline in gas pressures (signifying self-discharge) from the maximum of 211 psig. After 30 hours, however, the rate of pressure drop had declined to a very low level. Extrapolation of the pressure-time curve indicated a leveling off of gas pressures near 165 psig (corresponding to a state of charge near 20 amp-hrs). This result signifies that the maximum charge which the unit can effectively retain is approximately 20 amp-hrs. The self-discharge from higher states of charge most likely occurs via diffusion of and subsequent chemical reaction of the gases on the surfaces of the platinized nickel electrode.

The unit was subsequently discharged for 15 amp-hrs as described later in Section 3.11.

### 3.9 Float Charge Requirements

A series of float charge tests was conducted during the latter portion of this reporting period. The objective of these tests was to establish the float charge current required to maintain a given state of charge. The tests were conducted by charging the unit to a given state of charge at a fast rate (6 amps) and then reducing the current to a low float charge current and observing the change in pressure with time over an extended period of time. Steady-state gas pressures were usually obtained in a period of about 10 hours.

The results of these tests are shown in Fig. 5. The results indicate that very large float charge currents (in excess of 1 amp) would be required to maintain pressures greater than 220 psi (corresponding to a state of charge in excess of 25 amp-hrs). On the other hand, the



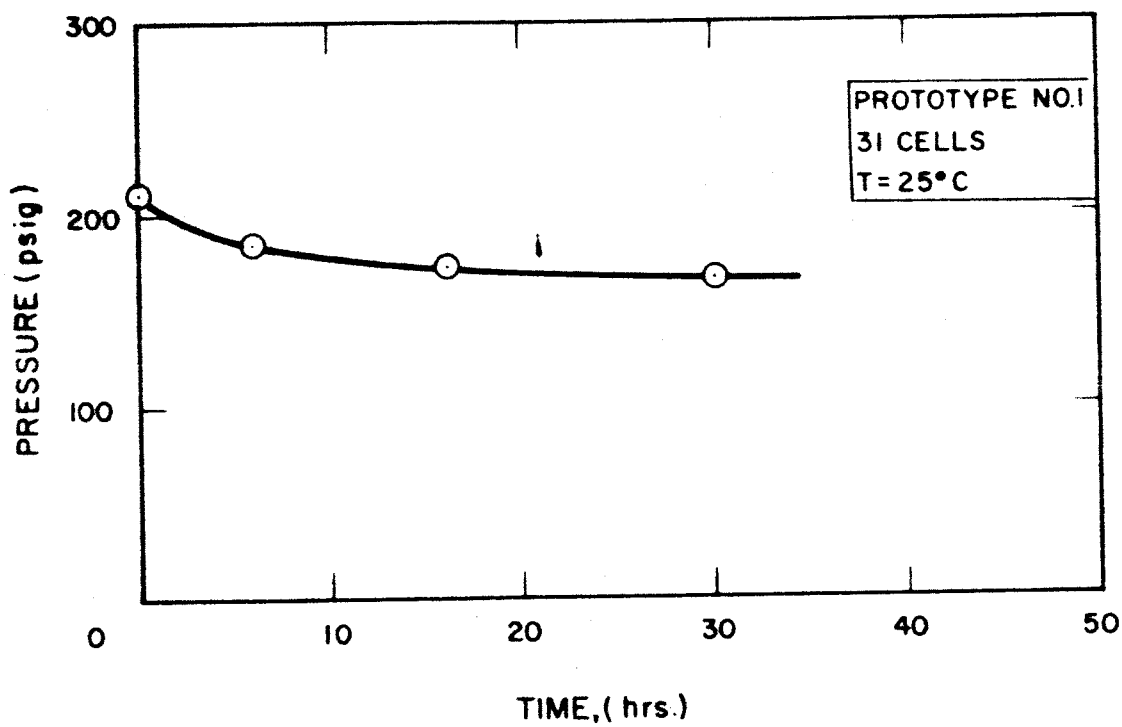


FIG. 4 SELF DISCHARGE CHARACTERISTICS

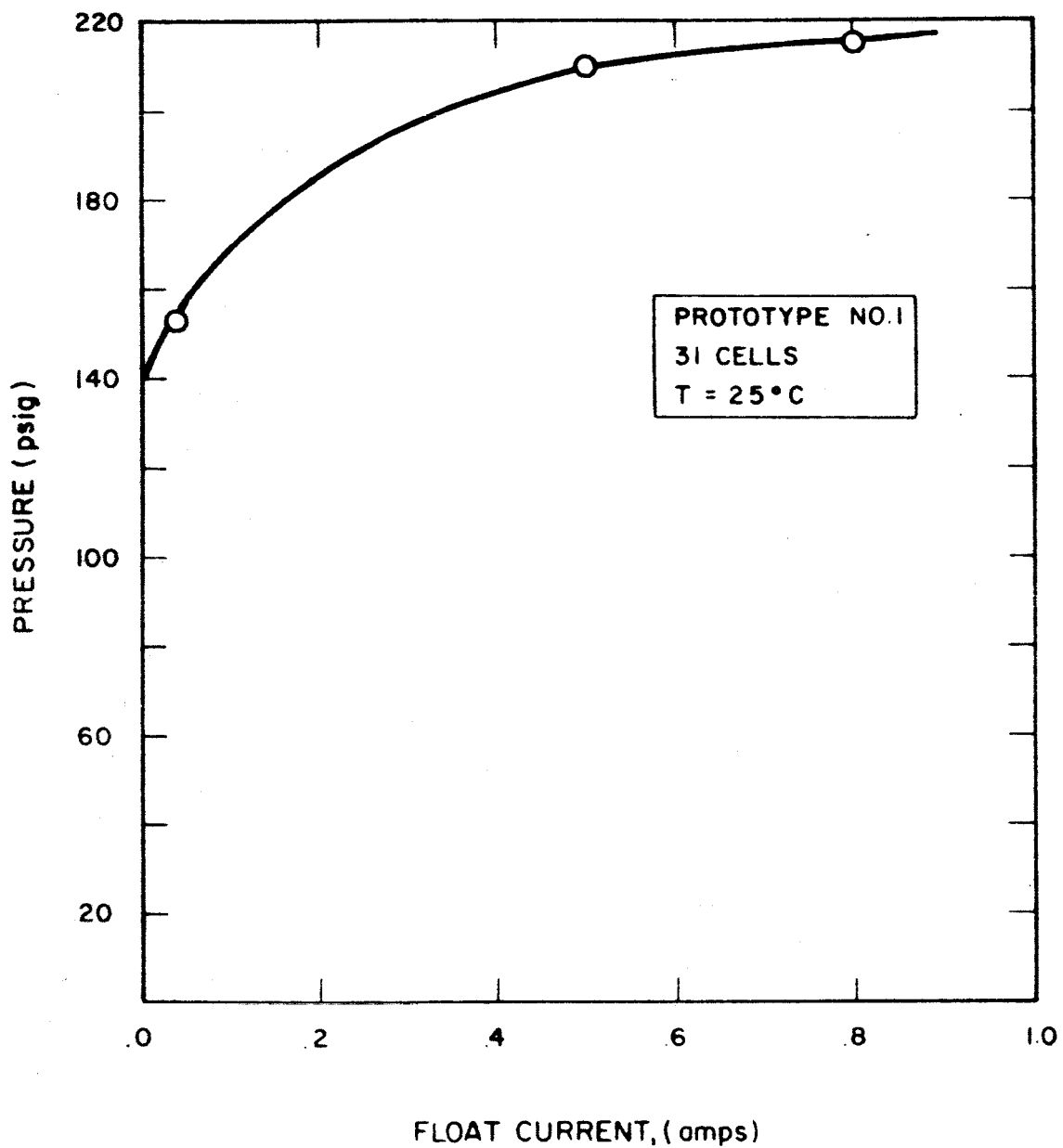


FIG. 5 FLOAT CHARGE REQUIREMENTS

results indicate that very minute float charge currents (approximately 50 ma) would be required to maintain gas pressures near 165 psig (corresponding to a state of charge near 20 amp-hrs).

### 3.10 Capacity

The capacity of the unit may be defined as the difference between the upper state of charge which the unit can maintain effectively over long periods of time and the lower state of discharge at which point the terminal voltage begins to decline rapidly on discharge at reasonable operating currents of at least 1 amp or greater.

The upper limit has already been established by the 30 hour stand test and the series of float charge tests. The results indicate that the upper limit varies from 20 amp-hrs with little or no float charge to 25 amp-hrs at which point the float charge requirements become excessive.

The lower limit **however**, has not clearly been established. Based on the results of the first 16 cycles (see Section 3.11), it would appear that the lower limit is approximately 8 amp-hrs. Based on this result then, it may tentatively be said that the capacity of this unit with a 50 m.a. float charge is approximately 15 amp-hrs. There are indications however that the lower limit may be dependent upon the initial flushing and assembly procedures and therefore the above results should not be considered conclusive. A significant phase of the testing during the latter stages of this program will be to establish the factors that control the lower limit.

### 3.11 Lower Limit Tests

One series of short cycles (numbers 9, 10 and 11) was conducted from the point where the lower limit was near 8 amp-hrs. These cycles consisted of a 10-minute charge at 5 amps followed by a continuous discharge at 2 amps until the terminal voltage fell rapidly from its plateau. The results of the tests indicated an output in terms of amp-hrs of nearly twice the input. The lower limit is thus seen to decline by this method of testing.

These tests add some support to the belief that the lower limit is caused by an accumulation of inerts within the electrodes, i.e., a short charge would force the inerts back into the gas chambers and thereby permit more pure gases to re-enter the cells on subsequent discharge. The presence of the inerts can be attributed to two possible sources: the first is that of the commercial grade hydrogen and oxygen gases which were used to flush the cylinders, and the second; that the air initially in the gas cylinders may have been inadequately flushed during startup.

These factors are currently being studied by the use of modified startup techniques. The technique involves the evacuation of the gas chambers by means of a vacuum pump to 25 inches of mercury vacuum followed by the introduction of research grade oxygen and prepurified hydrogen into their respective chambers. The process is repeated five times at which point it can be shown that the residual air concentration approaches that of the level of impurities within the high purity gases. The first cycle tests after this new startup procedure indicate a somewhat lower limit, however, the results will not be conclusive until additional cycle tests are completed.

### 3.12 Summary of Cycle Tests

A summary of all the cycle tests conducted on the first prototype is presented in Fig. 6. The reason for the selection of the given cycle depths and the particular sequence of cycles shown in the figure has been presented in the preceding section. For the sake of completeness however, a review of the cycle tests is presented below.

Cycle No. 1 was a preliminary test to establish the functionality of the recently completed unit. As indicated, the unit delivered only 7 amp-hrs of the 10 amp-hr input. The inability to discharge further was attributed to the low gas pressures (30 psig) near the end of discharge.

The purpose of Cycle No. 2 was to establish the maximum charge that the unit could effectively retain and deliver (see Section 3.8).

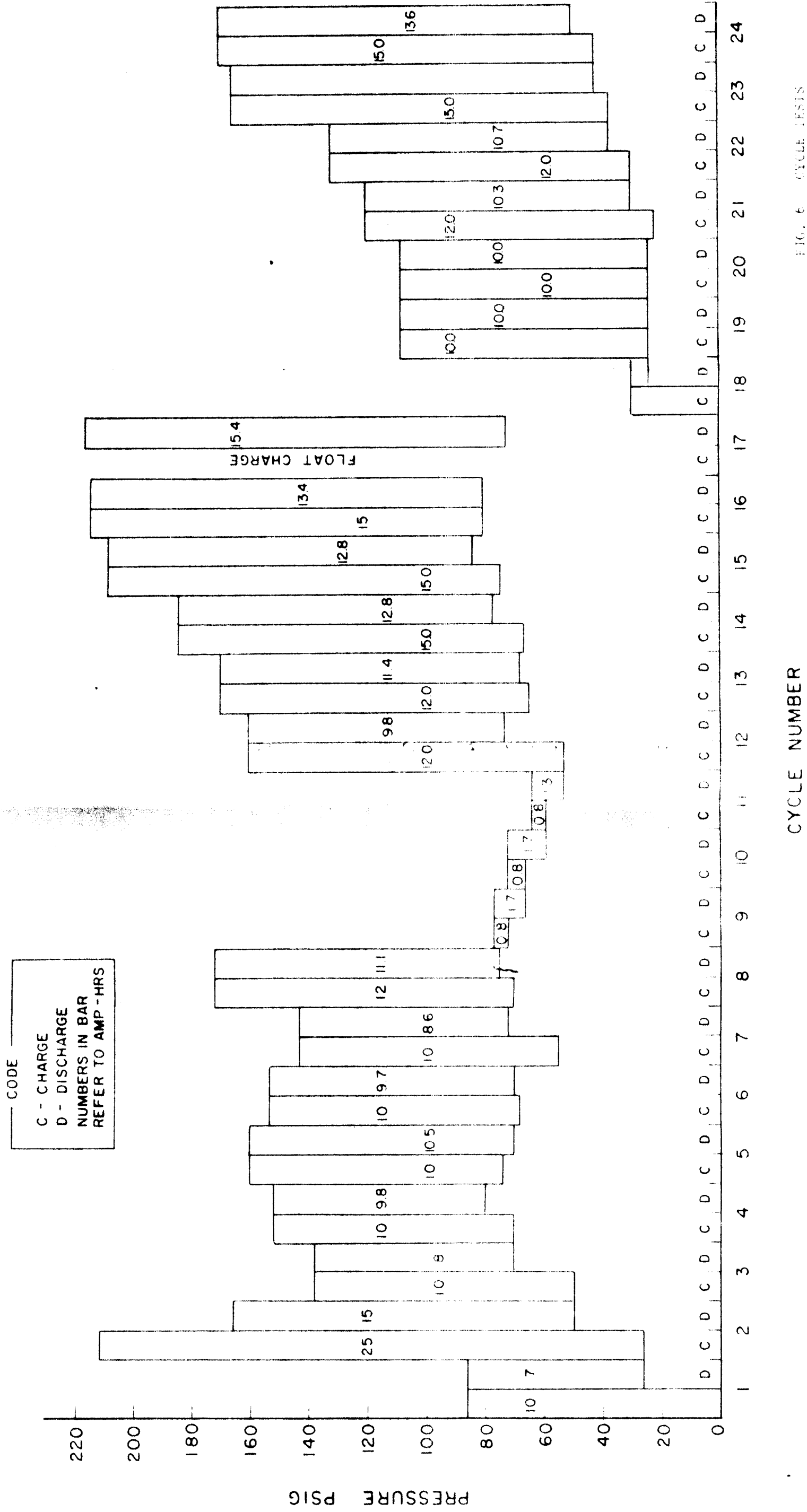


FIG. 6 CYCLE TESTS

CYCLE NUMBER

The cycle included a 30 hour stand before discharge period which lasted for 13 amp-hrs. The inability of the unit to discharge further (with residual gas pressures near 65 psig) was at first attributed to gas mixing which may have occurred during the self discharge period. In order to test this theory, the residual gases were vented to the atmosphere and were replaced with "fresh" hydrogen and oxygen gases from commercial gas cylinders. Upon application of a load, the unit was found to discharge an additional 2 amp-hrs. This result adds some support to the theory of gas mixing but is by no means conclusive.

Subsequently, a series of 10 amp-hr cycles (cycles 3 through 6) was initiated in order to observe any trend which might develop in regard to the raising or lowering of the output-input ratio. As indicated in Fig. 6, a trend of progressively higher output was noted for each of the above cycles. At the end of the sixth cycle, the testing process was interrupted for a two-day period in order to move to a new laboratory. This move necessitated the release of the residual gas pressures. Upon reinstallation at the new location, the gases were reapplied and another 10 amp-hr cycle (No. 7) was conducted.

Upon consultation with the Technical Monitor, it was decided to continue cycling at progressively higher inputs. The first such test consisted of a series of 12 amp-hr cycles (Numbers 8, 12 and 13). The second series was of 15 amp-hr duration (Numbers 14, 15 and 16). As indicated in the figure, higher outputs were obtained for higher inputs. The maximum output for the 15 amp-hr cycles was 13.8 amp-hrs. This latter result corresponds to a current efficiency of 92 percent.

The purpose of the series of short cycles Numbers 9, 10 and 11 was to test the theory of "inert gas buildup" as described in Section 3.11.

Upon further consultation with the Technical Monitor, it was decided to conduct the float charge tests as described in Section 3.9. The float charge and subsequent discharge were included in the chart as cycle No. 17.

The first series of cycles after the modified startup procedure are numbers 18 through 24. The results indicate some beneficial effects in regard to the lowering of the discharge limit, however, the results will not be conclusive until further tests are conducted.

#### 4. COMPONENT TESTING

If the "lower limit" studies establish a method for permitting complete discharge of the unit to the zero state of charge, then the maximum capacity of the first prototype unit will be approximately 20 amp-hrs. The latter value of capacity however is significantly less than the minimum design goal of 30 amp-hrs. In addition, if it is found that the zero state of charge cannot be reached, the resultant capacity of approximately 15 amp-hrs will be only one-half of the design goal.

The important question arises then as to how the upper limit may be increased in order to increase the overall capacity of the unit to at least the 30 amp-hr level. More specifically, the question may be asked as to the cause for the high self-discharge rate beyond the 20 amp-hr level. One possible answer to this question was presented in Section 3.8. There it was proposed that the self-discharge occurred via diffusion of the gases through the asbestos bed and subsequent chemical reaction on the platinized nickel electrodes. This answer appears reasonable in that the asbestos bed is relatively dry and permeable at the 20 amp-hr state of charge for it has lost approximately one-half of its initial water content by electrolysis. In addition, it is well known that hydrogen and oxygen gases do react chemically to form water on platinum black at room temperature.

Further examination of this problem supports this conclusion. The only other conceivable methods of self-discharge would be gas leaks or an internal short circuit. Numerous leak tests and stability of gas pressures at the 100 psi level over extended periods of time have ruled out the possibility of gas leaks. The known high open circuit voltage at the high state of charge (approximately 1.0 volts/cell) combined with the known voltage-current characteristics rules out the



possibility of an internal short circuit. The answer then must be chemical reaction via diffusion through the asbestos bed.

A convenient and simple method for solving this problem appears to be the use of a thicker electrolyte bed. It was reasoned that the use of such a bed would provide additional water for electrolysis and thereby increase the moisture content of the bed at the higher states of charge. The increased moisture content as well as the increased bed thickness would, of course, reduce the diffusion rate and consequently the self-discharge rate and thereby permit the maintenance of a higher state of charge.

The only absolute method for establishing the validity of such an idea would be to build a new prototype with increased bed thickness and measure its capacity. This method would, of course, be rather time consuming.

Fortunately, however, it had been noted on previous single cell tests (when run in the primary mode) that there were other phenomena associated with the high state of charge. The first of these was erratic discharge behavior, i.e., fluctuations of voltage on load. The second of these was the inability of the bed to withstand a slight pressure differential of less than 1 psi (as compared with the ability to withstand several psi in the uncharged state).

Consequently, single cells of the first prototype were machined to accommodate additional layers of electrolyte bed and the above characteristics were measured at various states of charge via the primary mode of operation. Erratic cell behavior and sensitivity to pressure differential above the 30 amp-hrs was found with three layers of asbestos and above 40 amp-hrs with four layers. These results compare with the similarly observed behavior between 20 and 25 amp-hrs for the currently employed two layers of asbestos. These results then would indicate that the minimum design goal of 30 amp-hrs could be attained by the use of four layers.

Before the use of the four layers was selected for the final units however, it was decided to compare the voltage-current characteristic

of the four layer cell with the two layer cell of the existing prototype. Typical discharge voltages at 4.0 amps were found to be approximately 0.75 volts/cell for four layers as compared with 0.80 volts/cell for two layers. These results indicate very small (6 percent) loss in voltage would be associated with the use of the two additional layers. The decision was therefore made to employ the four layers of asbestos in each cell of the final unit.

## 5. PROBLEM AREAS

One of the most severe problem areas that was discovered during the initial prototype tests was that of the internal electrical shorts. The short usually occurred in the midst of a charging cycle at which the terminal voltage was in the 50 to 60 volt range. Disassembly and examination revealed that the short had occurred across the insulated negative terminal which passes through the base plate. A black deposit and discolored metal indicated severe arcing had occurred at this terminal. The cause was traced to the phenolic bushing which insulates this terminal from the base plate. Evidently, over a period of time, this bushing had absorbed and reacted with some potassium hydroxide solution from the cell, causing the bushing to be a good conductor and leading to the arcing. The problem was tentatively solved on the prototype by the use of nylon bushings (which are inert to the KOH solution) and closer control over the amount of electrolyte added to the cells. The problem will be resolved on the final units by changing the location of the negative terminal to the flange on the hydrogen cylinder. This modification would limit the possibility of KOH contamination for this flange is remote to the cell stack. Teflon will be used to insulate the lead passing through the flange.

The phenomena of KOH contamination referred to above may also be a problem on the final units. Upon disassembly of the prototype, a slight water film containing traces of KOH was found (via a test with phenolphthalein) on both sides of the base plate as well as on the inside of both gas cylinders. Although this contamination caused no critical problem in regard to the operation of the prototype, it would most likely limit the performance of the final units. The reason for the latter is that the KOH will corrode the aluminum to form hydrogen resulting in

both mixing (if in the oxygen cylinder) and pressure unbalance (if in either cylinder); both phenomena of which are known to cause diminished cell performance.

In order to resolve this problem on the final units, two steps will be taken. First, the internal surfaces of the cylinders as well as the base plate will be coated with an alkali resistant finish, e.g., nickel plate or epoxy coating. Second, much closer control will be kept over the KOH level within the cells. A slightly lower ratio of the amount of electrolyte to the amount of asbestos may be used and special care will be taken in the initial assembly and preliminary testing when, it is believed, that the major portion of the contamination is introduced.

Another problem that has not yet been resolved is that of reproducibility of cell fabrication. As indicated in Section 3.3, the performance of one of the thirty-one cells (in terms of discharge voltage on load) was significantly below all of the others. Although there are several known causes for the above phenomena, the exact cause cannot be singled out. (Some of these causes are catalyst activity, restricted manifolds, electrode flooding, and high resistance contacts). Even though a great deal of care is taken to insure the uniformity of the raw materials, processing and assembly techniques, the problem has not yet been resolved. The only action which can be taken at the present time in regard to this problem is to replace the bad cell or cells with new ones. This problem of course points to the need for developing more selective component tests such as that for catalyst activity.

## 6. CONCLUSIONS

### 6.1 Power and Voltage

The power output of the first prototype ranges from 28 watts at 1 amp to 176 watts at 8 amps (for 31 cells). Typical operating voltages at 30 ma/cm<sup>2</sup> are 0.8 volts/cell on discharge and 1.64 volts/cell on charge.

### 6.2 Upper Capacity Limit

The upper capacity limit of this prototype is approximately 20 amp-hrs with little or no float charge. The float charge requirements increase rapidly with the state of charge beyond the 25 amp-hr level at which a float current of approximately 1 amp is required.

### 6.3 Increasing Capacity

The upper capacity limit may be significantly increased by the use of four instead of the currently employed two layers of asbestos electrolyte bed. The use of four layers would cause a small (6 percent) reduction in the discharge voltage at four amps.

### 6.4 Lower Discharge Limit

The cause for the inability of the first prototype to discharge below the 8 amp-hr level has not as yet been established. A strong possibility currently under investigation is that of the accumulation of inert gases within the electrodes.

### 6.5 Cycling Voltages

The charging voltage of the first prototype is relatively constant (with a few percent) from beginning to end of charge. The discharge voltage is also constant (with a few percent) for the major portion of the discharge period, but declines near the end of discharge (the extent of decline depends on the operating current).

#### 6.6 Cycling Temperatures

Internal steady-state operating temperatures are in the range of 10 to 15°C above room temperature for charge and 15 to 25°C above room temperature for discharge.

#### 6.7 Problem Areas

Important problem areas are internal electrical shorts, KOH contamination within the cylinders and base plate, and reproduceability of cell fabrication.

#### 6.8 Final Unit Development

Fabrication of the first unit is proceeding on schedule. Assembly of the first unit should begin early in February 1963. The fuel cell portions will contain 38 cells in each unit, and each cell will contain four(4) layers of asbestos with 1.2 gms of ~~20~~20-KOH/in<sup>2</sup>. The gas cylinders and base plate will be made of aluminum. The latter parts will be coated with a KOH resistant material. The units should have upper capacity limits of at least 30 amp-hrs and should discharge within the 25 to 35 volt range. Total weight of each unit will be approximately 80 pounds.

#### 7. PLANS FOR THE FOURTH QUARTER

The major portion of the activities during the fourth and final quarter will be devoted to the fabrication of the parts for, and assembly of, the final units. If all delivery and fabrication schedules are met, the assembly of the first unit should begin in the early part of February 1963 and the assembly of the second should begin in the latter portion of that month. This schedule will allow for a limited amount of preliminary testing and rework if necessary.

Testing of the first prototype will also be continued during this period. The major objective of these tests will be to evaluate methods for improving operation at the lower discharge limit.